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A COMPARISON OF KNEE MOMENTS AND FOOT STRIKE PATTERNS DURING A LATERAL CUTTING MANEUVER: SHOD VS. BAREFOOT

Keywords: barefoot, shod, lateral cutting, ACL

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Abstract

Non-contact anterior cruciate ligament (ACL) injuries often occur during lateral cutting maneuvers where extension, adduction, and external rotation create high loads on the ACL. The aim of this study was to examine knee moments and foot strike patterns during lateral cutting while shod (SD) and barefoot (BF). Fifteen NCAA Division III athletes (7 female and 8 male; age 20.2 ± 1.5 yr; mass 71.5 ± 11.3 kg; height, 1.7 ± .06 m) without lower limb pathologies were analyzed during 5 trials of 45 degree lateral cutting maneuvers for each limb in both BF and SD conditions with the approach speed at 4.3 m/s. Kinetic and kinematic data were collected using an eight-camera motion capture system and a force plate with collection rates at 240 Hz and 2400Hz respectively. Paired t-tests were used to determine differences conditions. The SD condition produced a significantly (p<0.05) greater peak adduction moment and cutting while BF caused a more anterior foot strike. Lateral cutting while BF places no more stress on the ACL than when SD. Our findings suggest that lateral cutting maneuvers while BF will not increase stress on the ACL.

Keywords: barefoot, shod, lateral cutting, ACL

Question:

Does performing a BF cutting maneuver increase risky mechanics that may stress the ACL?

Variables:

- Knee angles at initial contact
- Peak knee abduction
- Peak knee frontal plane moments
- Peak knee extension moments
- Peak GRF
- Max ROL

Introduction

Movements that cause nearly full knee extension, combined with external or internal tibial rotation, predispose an athlete to a noncontact ACL injury (Bencke & Zebis, 2011). Lateral cutting maneuvers have been directly related to causing non-contact ACL injuries (L. D. Besier T, Cochrane J, Ackland T, 2001; Houck, 2003). An abundant amount of research has focused on athletic movements when wearing shoes; however, less is known about athletic maneuvers while barefoot (BF).

BF running has been intensely examined; however, there has been minimal research involving other BF athletic maneuvers. Although BF running has become increasing popular, many sports are commonly played BF in less developed areas such as Brazil and Africa (Boshoff, 1997). Playing sports BF is becoming a more popular trend in the

United States via annual BF soccer tournaments and fundraisers (e.g. Portland Barefoot & World Soccer Festival, Grassroot Soccer). These events draw large numbers of players of various ages and experience levels, many of whom who do not normally perform athletic maneuvers BF.

An abundant amount of research has focused on athletic movements when wearing shoes; however, few studies have focused on athletic tasks while BF. A common athletic task while playing soccer is a cutting maneuver, which consists of a high-speed, lateral change of direction [5]. Although lateral cutting maneuvers are important to game play, such movements drastically increase the likelihood of injury particularly to the anterior cruciate ligament [6]. Maneuvers which include rapid deceleration with a fixed foot and the knee approximately 10-30° of flexion [6] have been identified as common mechanisms of non-contact ACL injury in athletes.

Certain knee mechanics that have been identified as risk factors associated with ACL injury incidence including: less knee flexion at initial contact, greater knee valgus motion, a greater knee extension moment, and a greater knee valgus moment {Hughes, 2014 #301}. These risk factors are specific to females as there is little evidence regarding ALC injury biomechanical risk factors specific to males (Alentorn-Geli, 2014). However, Benjaminse et al. (2011) suggested that biomechanical differences during cutting and jump landing maneuvers are not conclusively different between males and females. Furthermore a if a male were to perform a cut with these risky mechanics the ACL would still be stressed regardless of the gender of the athlete.

We hypothesize that the BF condition would have 1) no change in knee extension moments; 2) no change in knee angle of initial contact; 3) no change in peak knee abduction; 3) no change in peak knee frontal plane moments; 4) peak impact GRF will not change between conditions; and 4) maximal rate of loading will be greater in the BF condition.

Methods

Participants

Fifteen athletes from various NCAA Division III sports (e.g., basketball, soccer, lacrosse, etc…) without lower limb pathologies volunteered to participate in this study (7 female, 8 male; age 20.19 ± 1.38 yr; mass 71.46 ± 10.18 kg; height, 1.71 ± 0.06 m). All subjects read and signed the informed consent approved by the Institutional Human Subjects Review Board of the University of New England.

Procedures

Retro-reflective markers were placed on the medial and lateral malleoli, first and fifth metatarsal heads, and heels. Cluster markers were placed on the posterior pelvis, lateral thighs and lateral lower legs. The pelvis was constructed using a modified Helen Hayes pelvis (Davis, 1991). A regression formula was used to determine the hip joints (Bell, 1989). The knee joint was defined as the midpoint of the medial and lateral knee markers. The ankle joint was defined as the midpoint of the malleoli. Each segment was allowed six degrees of freedom. Shoes used for the shod condition were New Balance 623 (New

Balance, Boston, MA). Subjects were allowed to familiarize themselves with the cutting maneuver for each condition. Five trials of the lateral cutting maneuver were collected for each limb in both the SD and BF conditions. The order of the conditions was randomized. Speed for all trials was set at 4.3 m/s with a window of error being ± 5% of the target speed. Speed was selected based on pilot testing and the ability of our subject's success of completing the cutting maneuver. The speed was verified using Brower Photogates (Brower, Draper, USA). Trials outside this speed were not included in the analysis. Subjects were allowed an approach of approximately 8 m. The 45 degree angle was marked with tape on the track surface (Figure 1). The motion of each subject was tracked during the stance phase while completing a 45 degree lateral cutting maneuver with eight Oqus Series-3 cameras (Qualisys AB, Gothenburg, Sweden) set at 240Hz.

Cutting maneuvers were performed on a force plate (AMTI Watertown, MA) set at 2400Hz with an indoor rubber track covering affixed to the surface of the plate (Super X, All Sports Enterprises, Conshohocken, PA). Visual 3D (C-motion, Germantown, MD) was used to apply a Butterworth filter with a cutoff of 12 Hz to kinematic data, a filter with a cutoff of 50Hz to analog data (determined by retaining 95% of signal power through a fast Fourier transformation) [10], and calculate all variables.

Statistical Analysis

SPSS v21 (IBM, Chicago, Illinois) was used to run a repeated measures MANOVA (limb x condition) to determine statistical differences. Statistical significance was set at the $p \leq 0.05$ level of confidence.

Results

Cutting while barefoot produced greater knee flexion angles at initial contact ($p = 0.004$), less knee abduction ($p = 0.029$), less of a knee extension moment ($p = 0.005$), and subjects landed with a more anterior center of pressure ($p = 0.002$) than when shod (Table 1). The maximal knee extension moment was significantly greater ($p = 0.034$) in the non-dominant limb than the dominant limb (Table 1).

Discussion

The purpose of this study was to determine if peak knee moments and foot strike patterns were different between SD and BF conditions during lateral cutting maneuvers. Ours was the first study that examined athletic maneuvers between BF and SD scenarios and our study focused on the knee moments of extension, adduction, and external rotation during the WA and PPO phases that have been linked to ACL stress. We hypothesized the BF condition would have greater extension, adduction, and external rotation knee moments than the SD condition during the WA and PPO phases and that there will be no difference in foot strike patterns. Our findings; however, indicate that the peak knee extension and external rotation moments during the WA phase are no different when SD or BF. Furthermore, the SD condition produced a greater peak knee adduction moment during the WA phase. No differences in peak knee moments were found in the PPO phase. With regard to foot strike patterns, the BF condition had a more anterior center of pressure location at initial contact. The results of this study suggest that BF cutting places no greater torque on the knee than when SD.

Besier et al found that peak knee moments of extension, adduction, and external rotation during the WA and PPO phases of a lateral cutting maneuver created the highest load on the ACL, thus increasing the risk of a noncontact ACL injury (L. D. Besier T, Cochrane J, Ackland T, 2001). The most detrimental forces associated with noncontact ACL injuries include the combination of these knee movements along with a knee flexion angle of approximately 20-30º (Alentorn-Geli, et al., 2009). Paquette also suggested an increased risk for injury when there is no adaption period when shifting from SD to BF running (Paquette M., 2012). Our study found greater peak knee adduction moments in the SD condition during the WA phase while performing a cutting maneuver.

ACL injuries during lateral cutting usually occur early in the stance phase while decelerating (Koga, et al., 2010; Krosshaug, et al., 2007). Females are 2-8 times more likely to rupture their ACL than males (Agel, Arendt, & Bershadsky, 2005; Arendt & Dick, 1995). Females also produce greater knee adduction moments than males when performing a lateral cut (Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001), which is thought to be part of the mechanism responsible for the greater rate of ACL tears in females. A prospective study found that females who later ruptured their ACL had greater knee adduction moments during a single leg landing than those athletes who did not rupture their ACL (Hewett, et al., 2005). Stearns et al. also found great knee adduction moments when cutting in female soccer players who had ruptured their ACL than their healthy counterparts (Stearns & Pollard, 2013). When comparing our results to Stearns, our SD condition produced greater knee adduction moments (1.03 Nm/kg) than Stearns's healthy control group (0.80 Nm/kg), but less than the ACL reconstructed group (1.33 Nm/kg). It is also interesting to note that our BF condition produced less of a knee adduction moment (0.66 Nm/kg) than either Stearns's ACL reconstructed, or control groups. Even though we were not able to run statistical tests comparing Stearn's and our data, comparisons between the data demonstrate that performing the cutting maneuver BF was able to reduce the knee adduction moments back to a value similar to a healthy athlete.

Several key differences affect running mechanics when BF such as increased tactile awareness of the floor, loss of the cushioning of a shoe, and the loss of the raised heel of a shoe, all of which tend to lead to alterations in foot strike patterns (Lieberman, et al., 2010). The majority of the mechanical changes during BF running stem from the alteration in foot strike patterns. Similar to BF running, BF cutting shifted the center of pressure to a more anterior position (Lieberman, et al., 2010). Research has shown that running BF alters foot strike patterns and decreases knee extension joint moments (Paquette M., 2012). Our findings suggest that even during a multi-planar maneuver such as BF lateral cutting, alterations in foot strike patterns occur.

Conclusions

A limitation of this study is that the subjects rarely participated BF in field sports, so the results of this study would be more applicable to a population new to BF sports. Regardless of this limitation, cutting while BF altered foot strike patterns and resulted in less of a knee adduction moment. As Hewett et al found, greater knee adduction moments are predictive of an increased risk of ACL injury (Hewett, et al., 2005). These findings suggest that performing lateral cutting maneuvers BF does not increase risk of ACL rupture as compared to SD. As BF running continues to become increasingly popular, playing sports BF may become more prevalent. Furthermore, it is important to understand how other movements besides forward running affect the lower limbs.

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Figure 1: Lateral Cutting Course

Figure 2: Phases of Stance

Table 1: Comparison of Knee Mechanics between Shod and Barefoot, Mean (SD)

		Knee Flexion Angle at IC (degrees)	Peak Knee Valgus Angle (degrees)	Peak Knee Extension Moment (Nm/kg)	Peak Knee Valgus Moment (Nm/kg)	Center of Pressure at IC (m)
Shod	Dominant	-15.7 (5.7)	-6.5 (5.1)	2.20 (0.92)	-0.76 (0.35)	-0.05 (0.09)
	Non-dominant	-17.7 (5.9)	-5.4 (4.6)	2.54 (0.77)†	-0.74 (0.32)	-0.03 (0.08)
Barefoot	Dominant	-20.0 (5.3)*	-4.8 (4.1)*	2.09 (0.74)*	-0.73 (0.21)	0.03 (0.08)*
	Non-dominant	-21.6 (5.1)*	-4.7 (3.8)*	2.27 (0.88)†*	-0.91 (0.37)	0.05 (0.10)*

*Significantly different than Shod Condition

†Significantly different than Dominant Limb

IC = Initial Contact

Table 2: Intra-Class Correlations

		Knee Flexion Angle at IC	Peak Knee Valgus Angle	Peak Knee Extension Moment	Peak Knee Valgus Moment	Center of Pressure at IC
Shod	Dominant	0.906	0.995	0.984	0.875	0.731
	Non-dominant	0.885	0.883	0.984	0.886	0.874
Barefoot	Dominant	0.941	0.853	0.979	0.878	0.851
	Non-dominant	0.862	0.971	0.97	0.653	0.67

IC = Initial Contact